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Computing the Lexicon Morphological-Phonological Interface for Irish Sign Language Sign Realisation

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Abstract

The first modern linguistic analysis of a signed language was published in 1960 by William C. Stokoe, Jr., a professor of English at Gallaudet University, Washington DC, the only college for the deaf in the world. Nearly sixty years on, research in the area of sign language linguistics has established that signed languages are fully developed natural languages with their own syntax, morphology and phonology. The morphology and phonology of signed languages is concerned among with manual and non-manual features. These include handshapes, head, torso, eyebrow, eye, cheek, mouth, nose, chin and tongue movement and also movement of the shoulders. On application of various phonological rules these are used to represent the morphemes, phonemes, phonomorphemes and lexemes of Sign Language. This paper is concerned with determining the computational lexicon morphological-phonological interface of Irish Sign Language Sign (ISL) for sign realisation. We provide an outline of our proposed computational phonological parameters for ISL. These parameters are determined with a view to developing a lexicon architecture that is capable of representing the linguistic phenomena consistent with Sign Language and in particular to this research, ISL.

1 Introduction

Signs use visual imagery to convey ideas instead of single words. Stokoe (1960) described *signs* as being much more simultaneously organised than *words*. “Signs are not holistic units, but are made up of specific formational units: hand configuration, movement, and location.” Zenshan (2007) proposed that *signs* in sign language are situated at an equivalent level of organisation as words in spoken language and these units have psychological and cultural validity for their users. Following Brennan (1992), Leeson and Saeed (2012) identify *signs* in sign language as equivalent to *words* in spoken language in terms of grammatical role.

This paper describes and proposes computational phonological parameters necessary to represent ISL linguistically and in computational terms. We refer to Pustejovsky (1991) with regard to capturing lexical meaning using four levels of lexical representation. We propose an additional lexical representation level with regard to Pustejovsky's model in order to fully represent lexical meaning for Sign Language. We use Role and Reference Grammar (RRG) as the underlying theory of grammar for the development of our linguistic framework.

2 Motivation

In 2015 ISL is still not recognised by the Irish government and has no official status within Irish legislation. Deaf communities have their own culture, with their own values and their own language. This makes them a minority group, both culturally and linguistically. One consequence of this is that no linguistically motivated computational framework has ever been developed to describe the architecture of ISL. This type of framework has the potential to alleviate the communication barrier for members of the deaf community in computational terms by way of development of a 3D humanoid character capable of ISL synthesis. The use of signing avatar technology would provide members of the Deaf community access to important information in relation to education, employment and a myriad of other resources that are not currently available to members of the deaf community in Ireland (Murtagh, 2011a).

3 Three-Dimensional Humanoid Modelling for ISL Realisation

In terms of modality, ISL is communicated as a gestural-visual language as opposed to spoken language, which is communicated within an oral-auditory capacity. Due to the visual gestural nature of ISL, and the fact that ISL has no written or aural form, in order to communicate a SL utterance we must implement a humanoid model within three-dimensional (3D) space. Also in order to define a linguistically motivated computational model we must be able to refer to the various articulators (hands, fingers etc.) as these are what we use to articulate the various phonemes, morphemes and lexemes of an utterance. Murtagh (2011c) describes the development of a humanoid avatar for Sign Language realisation. The initial stage of avatar development involved the development of a skeleton referred to as an *armature*. The armature behaves in a similar fashion to the human skeleton. The bones of the armature are connected resulting in a controllable, intuitively movable character rig. We refer to various components within the joint hierarchy of this 3D humanoid model in our research into the morphological-phonological interface of ISL. Figure 1 below provides an overview of this hierarchy.

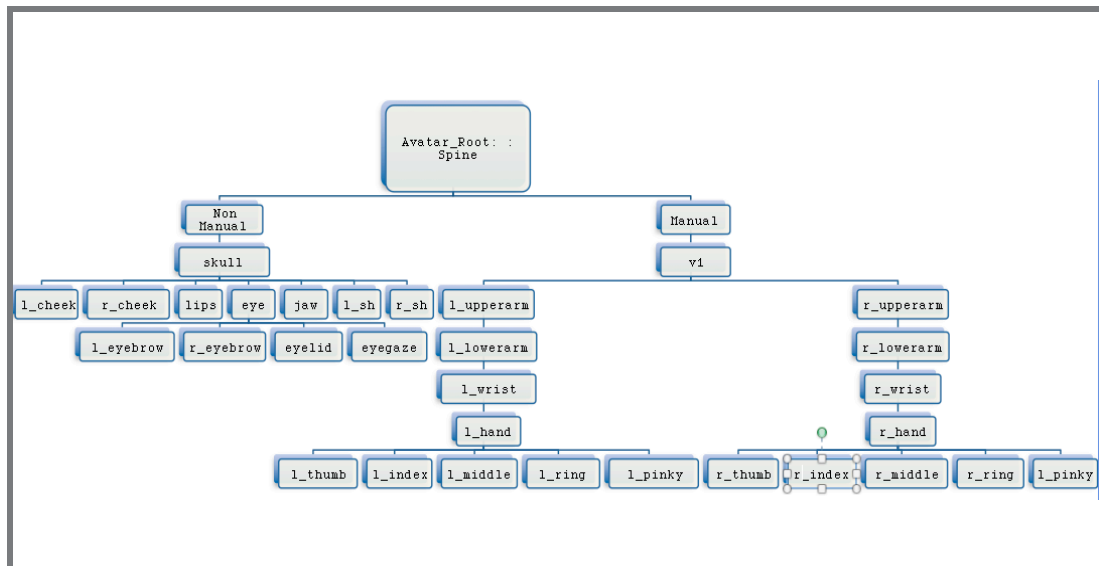


Figure 1: Overview of Avatar Joint Hierarchy (Murtagh, 2011c)

Once the armature was developed using the joint hierarchy illustrated in figure 1, a mesh for the avatar was attached, which resulted in an intuitively movable character rig. Figure 2, 3 and 4 below show examples of the armature, the mesh that is applied to the armature and the resulting avatar rig, from Murtagh (2011c).

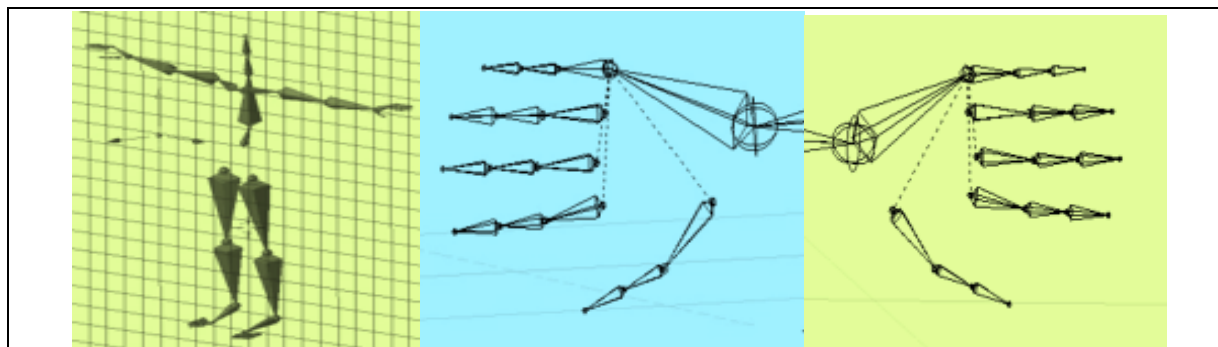


Figure 2: The Blender avatar rig and the armature of the left and the right hand respectively (Murtagh, 2011c)



Figure 3: Various orientations and views of the avatar right hand mesh (Murtagh, 2011c)

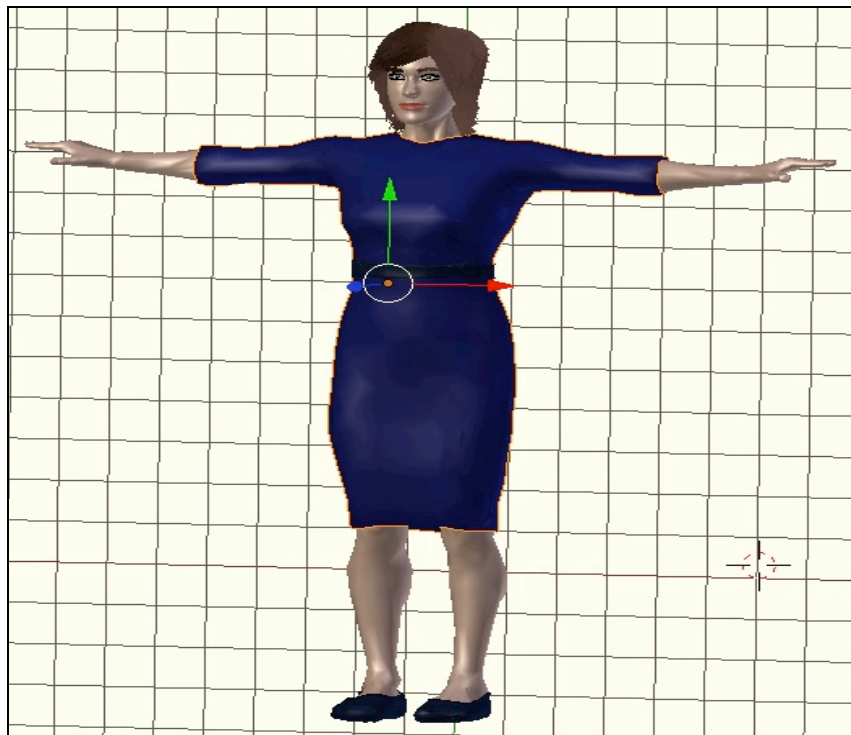


Figure 4: The 3D Humanoid Model (Murtagh, 2011c)

4 The Morphology of Irish Sign Language

4.1 Phonemes and Morphemes

Taub (2001) identified that there is an important difference between *signs* and *words* with regard to iconicity, where signs perform better at iconically depicting the concepts that they denote. Johnston and Schembri (1999) propose the term *phonomorpheme* as a descriptor for the dual nature of iconic signs. This term allows for the fact that iconic signs, contrary to the traditional linguistic division of phonemes and morphemes, can function simultaneously as both phonemes and morphemes. Meir (2012) also identifies that phonemes may be meaning-bearing and not meaningless within Sign Language.

4.2 Locus

A locus in Sign Language refers to a location in space in which a specific entity has been established (Liddell, 1990). The signer can establish an entity by articulating a lexical sign at a specific location in space. A signer can also produce a sign and then direct eyegaze or point to a location in space (Leeson and Saeed, 2012). Once established, an entity can be referred

to later in the discourse. Liddell (1990) describes how locus can also be situated on the signers body, in which case the location on the body that the locus is situated has been found to have phonological significance. Liddell refers to this as having an articulatory function. Locus may also refer to a particular place within 3D space. The signing space can be described as a stage on which entities are located. Signers use classifier predicates to represent real world entities and entities are located in relation to each other as they are in the real world (Leeson and Saeed, 2012). Sutton-Spence and Woll (1999) refer to this a topographical space. Leeson and Saeed (2012) describe how “entities can also be assigned a locus on the fingertips, with each fingertip then being activated as a locus that is co-referential with that entity”.

4.3 Verb Classification

Within the field of spoken languages, much research has been carried out within the domain of verb categorisation and classification. Levin (1993) provides a comprehensive classification of over 3000 verbs from spoken English based on properties shared meaning and behavior. Levin takes the view that the meaning of a verb affects its syntactic behavior and provides us with numerous verb classes by distinguishing verbs with similar syntactic behavior.

Verb classification within Sign Language is traditionally described according to Paddens tripartite classification of verbs based on American Sign Language (ASL) (Padden, 1988). Padden proposes that Sign Language verbs fall into one of three categories: *plain* verbs, *spatial* verbs and *agreement* verbs. The verb class can be differentiated between depending on the arguments that they encode.

4.3.1 Agreement

Agreement verbs, the class that denotes transfer, are said to encode the syntactic role of the arguments, as well as their person and number features, by the direction of the movement of the hands and the orientation of the palms. Agreement verb affixes show agreement with person or location.

4.3.2 Spatial

Padden (1988) describes spatial verbs as a class of verbs denoting motion and location in space. Spatial verbs encode the locations of locative arguments, the source and the goal based on the direction of movement of the hands. The shape of the path movement the hands are tracing is said to often depict the shape of the path that an object traverses in space.

4.3.3 Plain

According to Padden (1988), plain verbs, which constitute the default semantic class within ASL. Plain verbs do not encode any grammatical features of their arguments. They do not give morphological information of person and number by movement and do not show agreement with either subject or object. Plain verbs are uninflected and do not take agreement affixes.

4.3.4 Verb Classification for ISL

Figure 5, taken from Leeson and Saeed (2012) illustrates the morphological verb classes in ISL. Agreement verbs are further divided into those that show person agreement with subject/actor or object/undergoer and those whose affixes are controlled by locations (locative agreement).

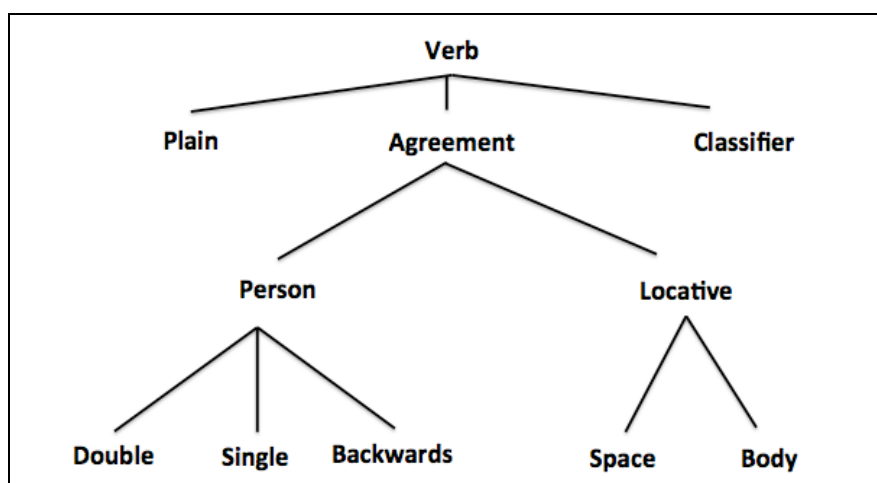


Figure 5: ISL Morphological Verb Classes (Leeson and Saeed, 2012)

4.4 Classifier Predicates

Classifier predicates or depicting handshapes are observed in almost all sign languages studied to date and form a well-researched topic in sign language linguistics” (Zwitserslood, 2012). Zwitserslood describes classifiers as “generally considered to be morphemes with a non-specific meaning, which are expressed by particular configurations of the manual articulator (or: hands) and which represent entities by denoting salient characteristics”. Leeson and Saeed (2012) define classifiers as “a set of handshapes (sometimes with movement components) that provide information about motion, location, handling and the visual-geometric description of entities in a signed language”. Leeson and Saeed refer to McDonnell (1996) who incorporates the six categories of classifier handshapes identified by Brennan (1994) to develop four broader categories of classifier predicates used in ISL. These are defined in table 1.

**Table 1: Four categories of classifier predicates in ISL (McDonnell, 1996)
(from Leeson and Saeed, 2012)**

Name	Description
Whole entity-CL stems	Includes discussion of hand configurations that refer to semantic size and shape, and instrumental categories.
Extension-CL stems	Includes reference to tracing size and shape configurations.
Handle entity-CL stems	Includes reference to handling and touch categories.
Body-CL stems	Where the signers body functions in a way that is similar to the way that handshape functions in certain two-handed configurations.

4.5 Noun plurals

ISL signs are inflected for grammatical information in similar ways to spoken language and while plural in English nouns is often marked by suffixation of a bound morpheme, for example –s in singular/plural pairs like girl/girls, in other languages plurals are marked by partial or full reduplication. Leeson and Saeed (2012) provide an example of noun pluralisation in ISL demonstrating the sign for HOUSE, which has been repeated three times HOUSE+++. This communicates the meaning ‘houses’.

4.6 Number

In ISL, person agreement verbs show a distinction between single and plural arguments in ISL. Leeson and Saeed (2012) also identify a general or non-specific plural, which is communicated through the articulation of a “smooth horizontal concave arc placed before the offset of the verb”. This plural may also be formed by a two handed sign in which each hand replicates the same form. Leeson and Saeed also identify an “exhaustive plural”, where the action is allocated to each member of a group by a series of short convex arcs. An example of an ISL sentence to illustrate an exhaustive plural would be: ‘I gave one to each of them’.

Leeson and Saeed also identify repetitions that modify the verb with regard to “attributive aspect”. In this case the repetition modifies the verb, but the focus is not “on the individuation of the plural argument”. Leeson and Saeed describe how this form occurs with a distributive sense, for example: ‘They all met each other (distributive)’.

4.7 Tense and Aspect

Leeson and Saeed (2012) describe aspect as an important inflectional category in ISL. Although tense is not marked morphologically on verbs in ISL, aspect allows speakers to relate situations in time with the view of being complete or incomplete. Leeson and Saeed describe how ISL shows similarities in findings with regard to aspectual morphology in ASL, which were identified by Klima and Bellugi (1979). Similar to ASL, ISL utilises modifications to the movement parameter to articulate aspectual marking. However, reduplication is particularly significant with regard to aspectual marking within ISL. Different verb types correspond to different dynamic situations. Leeson and Saeed describe an aspectually modified variant of the ISL punctual verb KNOCK. In this case iterative or repetitive aspect interacting with the verb produces a different interpretation.

Typically, within ISL, the verb KNOCK would have two repetitions associated with it. In the case identified by Leeson and Saeed, four repetitions signifies an aspectually modified variant of the verb, which implies that the knocking occurred repeatedly and with urgency. The movement parameter involves a straight line from close to the signer to the locus associated with the object (in this case a door). Leeson and Saeed also identify this “straight-line movement motif” repeated in other punctual verbs, for example HEART-BEATING +++++ (with multiple reiterations of the sign). Leeson and Saeed (2012) also identify the imperfective aspectual modification of durational verbs in ISL. In the case of the verb CRY, the inflection is articulated by a repeated circular movement. The meaning communicated is of the extended duration of the event.

4.8 Compounds

Sequential compounding in ISL occurs when signs are articulated one after the other in sequence. The compound formation involves the use of free morphemes and the meaning of the compound is generally distinct from the meaning of the phrase. Leeson and Saeed (2012) use the sign OLD_MOTHER in ISL, which means grandmother and not old mother to demonstrate this. They report that within ISL compound signs (which are usually made up of two free morphemes) usually involve a location change, and sometimes a change of handshape will also occur. The transition process between the ISL elements in the compound is smoother than the usual transition between separate signs. It is also noted that the duration of a compound sign is quicker than that of the production of individual morphemes.

4.9 Manner

The articulation of a sign representing a verb or an adjective may be modulated to provide further information regarding manner, intensity and also size. Adjectives may be modulated to provide information regarding scale. Leeson and Saeed (2012) identify that temporary states expressed by ISL verbs can also be modified, where movement of the verb is lengthened to convey the meaning of being for example “very” hungry or “very” tired.

5 The Phonetics and Phonology of Irish Sign Language

The visual gestural realisation of a word in Sign Language may involve the simultaneous and parallel expression of a varied number of manual and non-manual features. The phonology of Sign Languages is concerned with manual and non-manual features. Manual Features (MF) include handshapes across the dominant and non-dominant hand in simultaneous signed constructions. Non-Manual Features (NMF) include movement and tilt of head and shoulders, movement of eyes, eyelids, eyebrows, tongue, mouth shape and also blowing of cheeks. These are the morphemes, phonemes, phonomorphemes and lexemes of Sign Language.

5.1 The Handshapes of ISL

Murtagh (2011c) discusses the work of Ó Baoill and Matthews (2000) and describes how signs are formed within ISL by applying a set of phonological rules to a combination of handshapes and also how “identification of these handshapes and permissible combinations (noting that alteration of a single aspect provides the potential for expansion to the lexicon) provides us with an understanding of the building blocks of the formation of signs”. Figure 5 below, taken from Ó Baoill and Matthews, 2000, provides a subset of these the 66 different handshapes that are utilised within ISL in the formation of signed vocabulary.



Figure 6: A subset of the handshapes of ISL (Ó Baoill and Matthews, 2000)

5.2 The Signing Space

Ó Baoill and Matthews, 2000, describe the signing space as the space within which all signs must be articulated. The signing space usually extends from the waist outwards and includes the shoulders and the face. To ensure grammatical clarity, the signing space can be subdivided for meaning. Morphemes are articulated at particular points or *loci* in relation to the

signer for pronominal and anaphoric reference. Neutral space is the space immediately in front of the signer and close to the signer's body. It encompasses the area from the head to the waist and extends the width of the signer's body. Neutral space is the space that is used when producing the citation form of an item and generally does not act as a referent for particular or special meaning.

5.3 The Signs of ISL

As described in Murtagh, 2011, the signs of ISL can be divided into eight different categories according to the manner and mode of production. List 1 following illustrates these:

(1).

- a) One-handed signs, including body or near body contact during articulation.
- b) One-handed signs, where the sign is articulated in free space without any body contact.
- c) Two-handed signs having identical shape, where the hands touch during the articulation of the sign in space.
- d) Two-handed signs having identical shape, where the hands move in symmetry but without any contact taking place during the articulation of the sign in space.
- e) Two-handed signs having identical shape, where the hands perform a similar action and come in contact with the body.
- f) Two-handed signs having identical shape, where the hands are in contact during articulation, however, using one dominant articulator and one passive articulator.
- g) Two-handed signs showing a different shape, each hand having an active articulator and having equal importance.
- h) Two-handed signs showing a different shape, where the dominant hand (depending on whether the signer is left-handed or right-handed) is the active articulator and the other hand is the subordinate or passive articulator.

5.4 Non-Manual Features

As discussed in Murtagh (2011a) NMF consist of various facial expressions such as movement of the head, torso, eyebrow, eye, cheek, mouth, nose, chin and tongue and also movement of the shoulders. While NMF are normally accompanied by a signed lexical item, they can be used to communicate meaning independent to manual accompaniment. The following list identified by Ó Baoill and Matthews, 2000, provides an overview of all the relevant functions provided by ISL NMF.

(2)

- a) To show the degrees of emotion
- b) To denote intensification or modulation
- c) To distinguish declarative or interrogative sentences
- d) To denote negation
- e) To define topic or comment structures
- f) To indicate conditional clauses
- g) To show sarcasm

5.5 Handshape in ISL

Murtagh (2011a) discusses William Stokoe, (1960) and his identification of the various parameters which are relevant for the analysis of sign language. He suggested that the articulation of a sign encompassed three different parameters. A designator, which was used to refer to the specific combination of hand configuration. A tabulation, used to refer to the

location of the hands, and a signation used to refer to the movement of the hands. Stokoe referred to these parameters as *cheremes*, the signed equivalent of phonemes.

Later research refers to the parameters of sign language as *handshape*, *location* and *movement*, (Sutton-Spence & Woll 1999, Valli & Lucas, 1995). Battison, (1974) claimed that a fourth parameter is necessary in order to be able to fully transcribe signs. This fourth parameter referred to as orientation denotes the orientation of the hands and fingers during the articulation of the sign.

The HamNoSys inventory of handshapes from the university of Hamburg, has been adopted internationally by many phonologists, however, Thorvaldsdottir (2010) identifies an issue that arises with the use of this international database of handshapes to represent ISL, is that it doesn't necessarily capture the range of ISL-specific handshapes that arise. Another issue with the use of an international inventory of handshapes is that there are phonetic variants within ISL that are not represented in this international database of handshapes.

6 ISL Computational Phonological Parameters

Taking into consideration the various information pertaining to the morphology and phonology of ISL we propose the following computational phonological parameters with regard to the development of a lexicon architecture capable of accommodating the various information pertinent to ISL. We define various x,y,z co-ordinates within 3D space, where x represents a value for the horizontal axis, y represents a value for the vertical axis and z represents a value for the axis that moves towards you or away from you.

6.1 Manual Feature Computational Phonological Parameters

The following sections describe the computational phonological parameters for ISL manual features (MF).

6.1.1 Handshape

We have identified the 66 handshapes of ISL proposed by O'Baoill and Matthews (2002).

With regard to architecture of our lexicon we now define in computational terms the various articulators used to create various hand configurations for ISL communication. We define these articulators once, referring to the hand, but it is important to note that the theory applies to both the left and the right hand. The handshape parameter refers to parameters that allow various configurations of the hand within 3D space. This must include four separate x,y,z co-ordinates, each representing an Inverse Kinematic (IK) driver for the four fingers(f1, f2, f3, f4) and also parameters that accommodate the configuration for the thumb(x,y,z).

We must consider that the thumb can rotate 360 degrees around a central axis and it can also move along a line in an arc shape towards the palm of the hand or towards an overlap of a closed fist. The thumb can also align itself along in an arc shape where it is spread along the arc or sitting parallel to the index finger. While the thumb is in this position the fingers may be open or in a fist shape.

It is assumed that the thumb has been developed and constrained within 3D space to reflect similar capabilities to a normal human hand thumb movement. A default resting handshape will be defined to represent the default resting handshape in 3D space.

Table 2 provides the proposed computational phonological parameters for hand configuration. Figure 7 illustrates the various x, y, z co-ordinates referred to in table 2 above, where (x, y, z) refers to the IK driver situated on the tip of the armature fingers and thumb.

Table 2: Hand configuration computational phonological parameters of ISL

Digit	Parameter	Description
Little finger	$f4Shape(x, y, z)$	IK driver location for configuration of the little finger.
Ring finger	$f3Shape(x, y, z)$	IK driver location for configuration of the ring finger.
Middle finger	$f2Shape(x, y, z)$	IK driver location for configuration of the middle finger.
Index finger	$f1Shape(x, y, z)$	IK driver location for configuration of the index finger.
Thumb	$tShapeR(x, y, z)$ $hShapeClosed(f1, f2, f3, f4)$ $hShapeOpen(f1, f2, f3, f4)$	IK driver location for configuration of the thumb with regard to rotation. The hand may be open or in a fist shape.
Thumb	$tShapeA(x, y, z)$ $hShapeClosed(f1, f2, f3, f4)$ $hShapeOpen(f1, f2, f3, f4)$	IK driver location for configuration of the thumb with regard to movement along arc towards hand. The hand may be open or in a fist shape.
Thumb	$tShapeP(x, y, z)$ $hShapeClosed(f1, f2, f3, f4)$ $hShapeOpen(f1, f2, f3, f4)$	IK driver location for configuration of the thumb with regard to movement along arc from a spread position to parallel with the index finger. The hand may be open or in a fist shape.

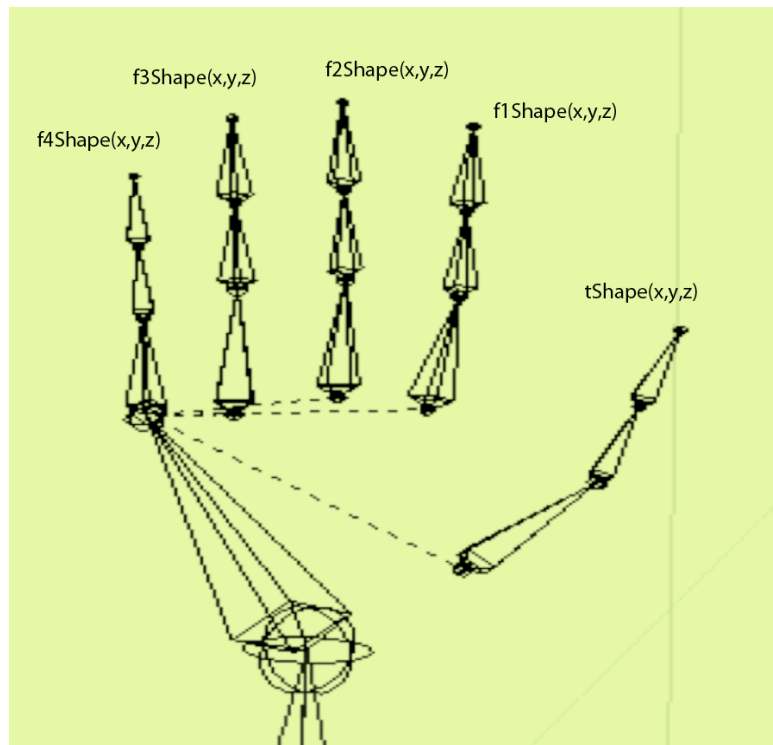


Figure 7: 3D-humanoid hand armature and the associated computational parameters for our lexicon architecture

6.1.2 Orientation

This parameter refers to the orientation of the palm of the hand. Due to human skeletal constraints, the palm orientation parameter also accounts for the orientation of the wrist and the forearm as these are children nodes with regard to the orientation of the palm and are therefore constrained to reflect the same orientation as the palm of the hand. The orientation parameter allows us to rotate the palm of the hand, the wrist and the forearm around any of the x, y or z axis within 3D space. We set out by defining a default resting position of our palms in 3D space $p_{(x,y,z)}$. This position sees the elbows tucked in by our sides and forearms pointing forward along the z-axis with the palms of the left hand and the right hand facing one another. Based on this initial position and due to human skeletal constraints, the palm, wrist and forearm can rotate from this position anywhere from zero to 90 degrees in a clockwise direction. And also from this default position anywhere from zero to 90 degrees in an anti-clockwise direction around the z-axis. Depending on the positioning of the forearm parameter $f1...f8$, which are defined in section 6.1.4, the rotation of the palm, wrist and forearm can rotate about any of the x, y or z axis from +1 degree to +90 degrees or from -1 degree to -90 degrees from our initial orientation $p_{(x,y,z)}$. The axis that we will rotate around is calculated based on the positioning of the forearm.

6.1.3 Orientation

This parameter refers to the hand movement or rotation of the hand in relation to the wrist. When the wrist rotates from the default resting position the hand can pivot on the wrist joint upwards to an angle of 80 degrees and it can also pivot from the default resting position downwards to an angle of 80 degrees. The wrist can also pivot from the default resting position to the left and to the right 20 degrees respectively. These movement constraints will be applied to reflect human skeletal movement. Parameters for the wrist movement can be defined based on the following figure where $w_i(x,y,z)$ represents our default resting position for the wrist and $w1(x,y,z)$, $w2(x,y,z)$, $w3(x,y,z)$, $w4(x,y,z)$ represent values for possible wrist movements along four different paths. Figure 7 provides an illustration of the orientation computational parameters.

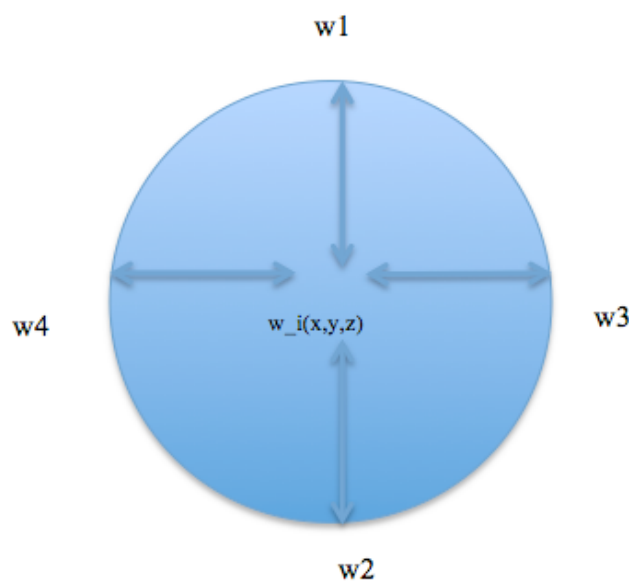


Figure 8: Hand movement parameters from initial position $w_i(x,y,z)$ to human skeletal constraint $w1....w4 (x,y,z)$ in relation to the wrist joint.

6.1.4 Forearm

This parameter refers to the movement of the forearm in relation to the elbow joint. We refer to the initial position of our forearm as our initial point $f_i(x,y,z)$, which will be set to a given parameter for both the left and right forearm. This will initially be set to a value that represents the forearm in its default resting position. This parameter will be over-written as each event within an utterance is realised within our framework, in which case the $f1....f8$ parameter will become the initial parameter and new values for $f1....f8$ will be set depending on the next MF event to be realised.

We propose that in relation to the elbow, the forearm, which includes the wrist, hand and fingers as children nodes and are therefore bound to the forearm, can move in 8 possible directions within our signing space in order to articulate a manual sign. These eight forearm movement parameters can be mapped to the 8 parameters outlined in the following figure, where the points $f1....f8$ define a line of movement in 3D space starting with the forearm in an initial position $f_i(x,y,z)$ and then moving in the direction of our chosen parameter $f1....f8$. The forearm movement can stop at any location along any of the eight parameters $f1....f8$. Forearm movement is constrained to terminate at the endpoint of the parameter $f1....f8$, which is the human skeletal constraint on forearm movement applied to the avatar.

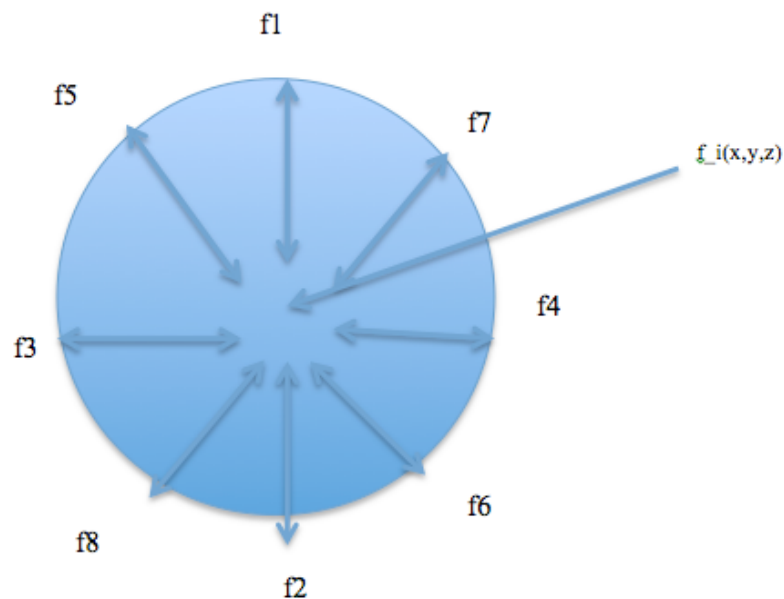


Figure 9: Forearm movement parameters from initial position $f_i(x,y,z)$ to human skeletal constraint $f1....f8(x,y,z)$ in relation to the elbow joint.

Similar to the forearm parameter in relation to the elbow joint, the upper arm parameter refers to the movement of the upper arm in relation to the shoulder joint. We refer to the default resting position of our upper arm as our zero point $(0,0,0)$ and from here we propose that the upper arm which includes the elbow, the forearm, the wrist, the hand and the fingers as children nodes can move in eight possible directions within our signing space in order to articulate a manual sign. These eight upper arm movement parameters can be mapped to any of eight parameters outlined in figure 10.

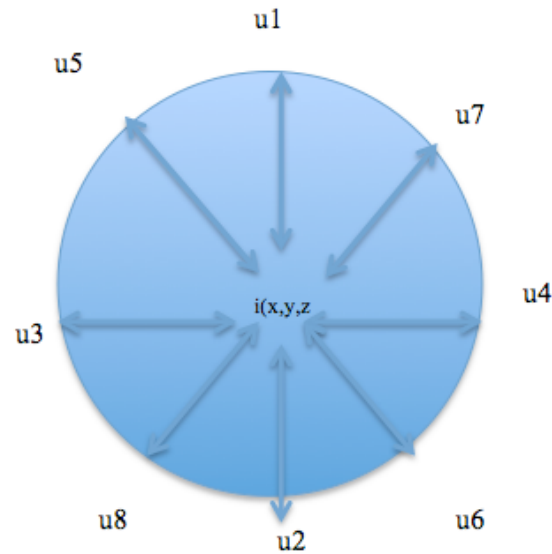


Figure 10: Upper arm movement parameters from initial position $u_i(x,y,z)$ to human skeletal constraint $u1....u8 (x,y,z)$ in relation to the shoulder.

6.1.5 Location

The location or tab at which a sign is realised within 3D space is significant with regard to the syntax and semantics of the articulation in ISL also. One example of this for ISL would be for body anchored minimal pairs “MY” and “STUPID”, where the handshape used is the same and the feature that changes meaning is the location feature. “MY” has the signer’s chest as a tab, whereas “STUPID” has the forehead as a tab. Our framework will take into account four different body anchored spatial locations: the head, the arms, the trunk and the hands. We also define spatial area around of the signer’s body. For the purpose of computational modelling, we have divided the body anchored tabs into a separate category to the spatial signing space tabs. Each of the locations or tabs can be further divided into individual subcategories. The following figure illustrates our proposed hierarchical division for the first two levels.

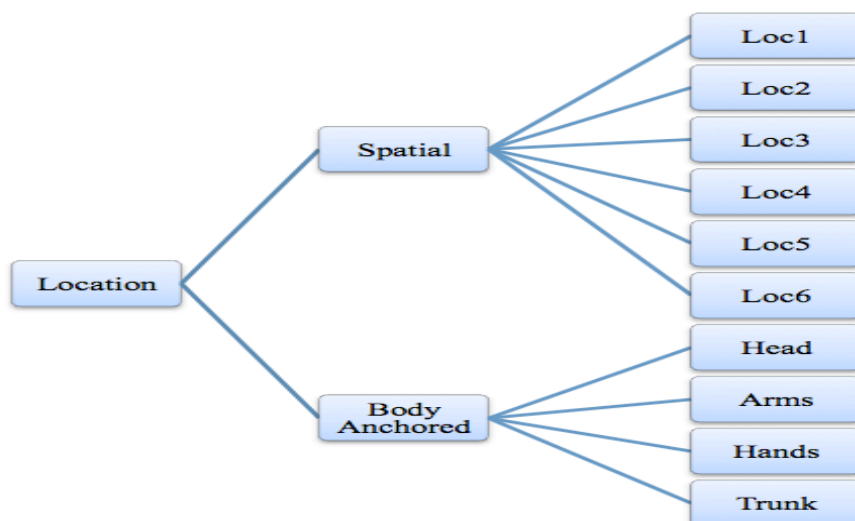


Figure 11: Location or tab parameter sub-categories

Due to the fact that within ISL an entity may be assigned a locus on the fingertips, with each fingertip then being activated as a locus that is co-referential with that entity, we must also consider these and assign the fingers of the hands as a subcategory of the hand tab category.

Table 3 illustrates the ISL body anchored location categories to include our comprehensive listing of subcategories.

For computational ease of modeling we have divided our spatial locations within the signing space into three tiers. The upper tier refers to above eye level, the mid tier refers to the level of neutral space in front of the signer at mid torso level and the lower space refers to the tier below torso level. The diagram following illustrates our computational parameters for spatial location with regard to our ISL Lexicon architecture.

6.1.6 Event Duration

The duration that it takes to articulate ISL MF phonological parameters and also the point at which these phonological parameters are articulated relative to the overall timeline of an articulation is critical to the communication process. This is also similar and true for ISL NMF phonological parameters. It is proposed that a parameter, henceforth termed event duration will be utilised in our linguistically motivated computational framework. Event duration will act as a meta-data repository pertaining to timing or temporal information. The event duration parameter will be utilised as an attribute within our framework in conjunction with every phonological parameter, both MF and NMF. It will represent the duration or time taken for any given MF or NMF phonological parameter to be realised.

The visual gestural realisation of an ISL MF and NMF phonological parameter is considered to be an event within our computational framework. The realisation of each event has a specific duration bound to it. This can be referred to as an event duration. This temporal parameter will play a central role within our framework in relation to the amount of specified time allowed for the various MF and NMF phonological parameter events to articulate various information in relation to an ISL utterance.

Table 3: Hand configuration computational phonological parameters of ISL

Tab	Subcategory
head	hair, topHead, backHead, leftTemple, rightTemple, leftEar, rightEar, leftCheek, rightCheek, nose, chin, forehead, mouth, neck
arm	rightShoulder, leftShoulder, rightUpper, leftUpper, rightElbow, leftElbow, rightLower, leftLower, rightWristTop, leftWristTop, rightWristPalm, leftWristPalm, rightWristRightSide, RightWristLeftSide, LeftWristRightSide, LeftWristLeftSide
hand	rightBack, leftBack, rightPalm, leftPalm, rightIndexup, leftIndexUp, Lf1(x,y,z), Lf2(x,y,z), Lf3(x,y,z), Lf4(x,y,z), Lt(x,y,z), Rf1(x,y,z), Rf2(x,y,z), Rf3(x,y,z), Rf4(x,y,z), Rt(x,y,z)
trunk	chestCentre, chestHeart, tummy

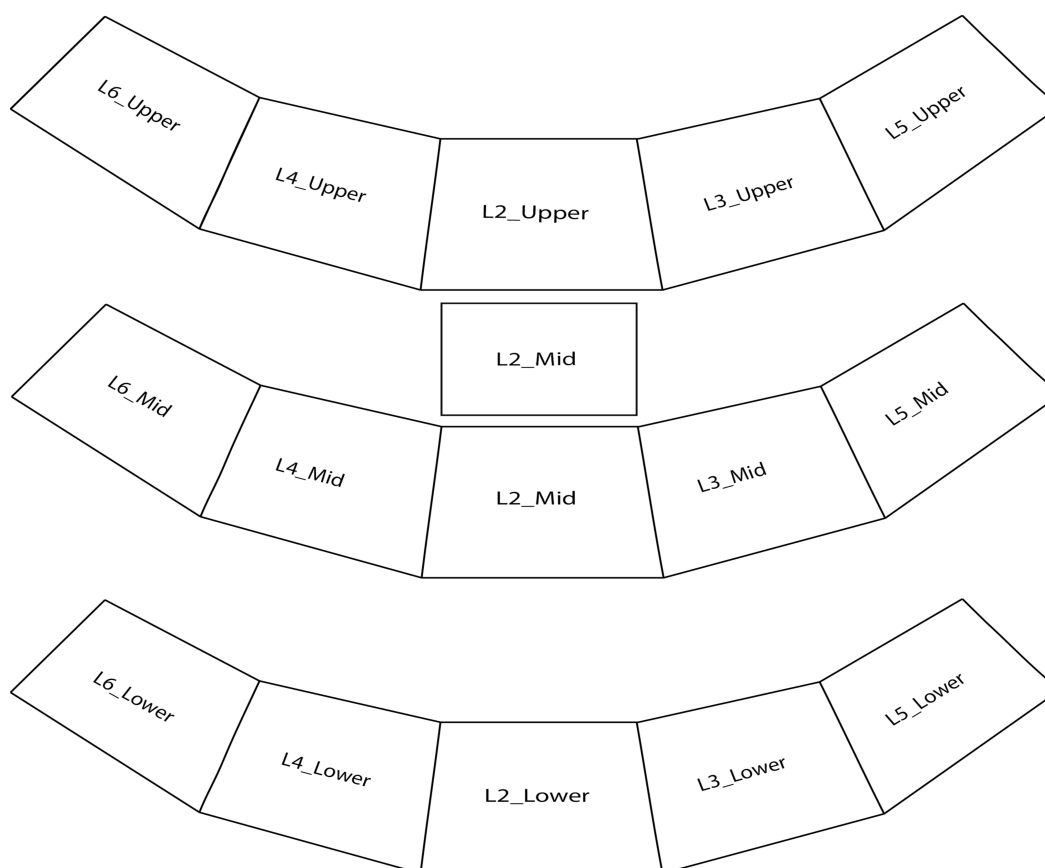


Figure 12: Computational parameters for spatial location with regard to our ISL Lexicon architecture

6.1.7 Timeline

A second temporal parameter, which must also be considered at this stage, is a *timeline* parameter. Not to be confused with the event duration parameter, which defines the time taken to realise any given MF or NMF phonological parameter within an utterance, the *timeline* parameter refers to a linear timeline representing the time taken from the moment an ISL utterance begins until the moment an entire utterance or articulation is completed or terminates. An utterance refers in this case to an ISL lexeme, phrase or sentence that communicates something meaningful.

The timeline parameter will play a central role within our computational framework as it is responsible for the ordering or sequence in which each phonological parameter event will be realised. The timeline parameter will assign specific temporal information to every phonological parameter defining at which point along the overall timeline any given phonological parameter or event may be realised. This parameter will allow us to synchronise the order in which each parameter will be articulated and also allow for the concurrent articulation of parameters when this is necessary.

Due to the visual gestural modality of ISL within 3D space, the event duration and timeline parameters are central components within our computational framework, providing essential temporal information that is relevant and bound to every phonological parameter. These parameters will enable the realisation of a credible, plausible and comprehensible ISL utterance articulated in 3D space.

6.2 Non-Manual Feature Computational Phonological Parameters

The NMF phonological parameters for our computational lexicon architecture are illustrated in table 4 below. It is anticipated that the NMF computational phonological parameters will be held in a repository within our framework architecture and represented as shape keys. These shape keys containing transformations of our 3D humanoid model mesh to reflect the NMF phonological parameter may be triggered when an event occurs within an utterance that requires any of the NMF illustrated in table 4 to be articulated.

7 Lexical Meaning for ISL

Pustejovsky (1995) defines the Generative Lexicon (GL) as a theory of linguistic semantics which focuses on the distributed nature of compositionality in natural language. According to Aristotle, there are four basic factors or causes by which an object can be described (Kronlid, 2003). These are outlined in table 5.

Prior to GL theory, lexical decomposition theories assumed a fixed set of primitives with regard to a word and then operated within this set in an exhaustive fashion to capture the meaning of all words within a language. Lexical ambiguity was accounted for by adding more than one word entry into the lexicon. Pustejovsky proposed that “rather than assuming a fixed set of primitives, let us assume a fixed number of generative devices that can be seen as constructing semantic expressions” (Pustejovsky, 1991).

Pustejovsky proposes that by assuming four levels of representation, as illustrated in table 6, we could best capture lexical meaning.

Pustejovsky defines qualia structures as the modes of explanation associated with a word or phrase. Qualia provide a description of the meaning of lexical items in terms of four roles. Table 7 provides an outline of these.

Table 4: Computational parameters for ISL NMF

ISL NMF Phonological Parameter	ISL NMF Phoneme
Head	nod, shake, tilt_left, tilt_right, turn_left, turn_right, chin_chest, chin_l_shoulder, chin_r_shoulder
EyeBrow (left and right simultaneous)	neutral, frown, arch
EyeLids (left and right simultaneous)	neutral, wide, squint, blink, closed
EyeGaze(left and right simultaneous)	neutral, left, right, up, down, left_up, left_down, right_up, right_down, locus
Cheek (left and right simultaneous)	Suck_in, blow
Mouth	neutral, open_wide, closed_tight, smile_teeth, smile_teeth_wide, smile_closed, round_open, round_closed
*Tongue	in, out_pointed_1, out_pointed_2, out_pointed_3, out_round_1, out_round_2, out_round_3,
R_Shoulder	neutral, up, down
L_Shoulder	neutral, up, down

* With regard to the tongue phonological parameter, the values 1, 2 and 3 in relation to pointed and round define the percentage of the tongue which will protrude past the lips. 1 represents 10%, 2 represents 60 % and 3 represents 100% protrusion.

Table 5: The four basic factors by which an object can be described (Aristotle, Kronlid, 2003)

Cause	Description
<i>Material</i>	The material an object is made of.
<i>Agentive</i>	The source of movement, creation or change.
<i>Formal</i>	Its form or type.
<i>Final</i>	Its purpose, intention or aim.

Table 6: Lexical meaning: four levels of lexical representation (Pustejovsky, 1991)

Lexical Representation Level	Description
<i>Argument Structure</i>	The behaviour of a word as a function, with its arity specified. This is the predicate argument structure for a word, which indicates how it maps to syntactic expressions.
<i>Event Structure</i>	Identification of the particular event type (in the sense of Vendler (1967)) for a word or phrase: e.g. as state, process, or transition.
<i>Qualia Structure</i>	The essential attributes of an object as defined by the lexical item.
<i>Inheritance Structure</i>	How the word is globally related to other concepts in the lexicon.

Table 7: Qualia structure roles (Pustejovsky, 1991)

Role	Description
Constitutive	Describing physical properties of an object, i.e. its weight, material as well as parts and components.
Agentive	Describing factors involved in the bringing about of an object, i.e. its creator or the causal chain leading to its creation.
Formal	Describing the properties that distinguish an object in a larger domain, i.e. orientation, magnitude, shape and dimensionality.
Telic	Describing the purpose or function of an object.

It was initially suggested that in order to create a lexicon architecture, which is sufficiently rich and universal in nature to capture the linguistic phenomena persistent to ISL, the theory of qualia should be extended. On further investigation it is now proposed that rather than extending the theory of qualia, we must develop an entirely new level of representation for lexical meaning to capture these linguistic phenomena and truly represent and accommodate Sign Language at the lexical semantic level.

Computational phonological parameters have been defined here and it is proposed that these parameters and their respective subcategories be represented in a new level of lexical representation for Sign Language referred to as *Phonological Level*. Phonological level refers solely to the lexical meaning of signed languages and specifically to the level of lexical meaning for Sign Language in which the essential (computational) phonological parameters of an object as defined by the lexical item are captured.

Table 8 illustrates the four levels of lexical meaning proposed by Pustejovsky (1991) and an additional *phonological structure* level, which has been proposed in relation to our research.

Table 8: Lexical meaning - five levels of lexical representation for Sign Language (An extension of Pustejovsky, 1991).

Lexical Representation Level	Description
<i>Argument Structure</i>	The behaviour of a word as a function, with its arity specified. This is the predicate argument structure for a word, which indicates how it maps to syntactic expressions.
<i>Event Structure</i>	Identification of the particular event type (in the sense of Vendler (1967)) for a word or phrase: e.g. as state, process, or transition.
<i>Qualia Structure</i>	The essential attributes of an object as defined by the lexical item.
<i>Inheritance Structure</i>	How the word is globally related to other concepts in the lexicon.
<i>Phonological Structure</i>	The essential (computational) phonological parameters of an object as defined by the lexical item.

8 Discussion and Conclusion

Within this research we have identified and defined the morphology and phonology of ISL. We have considered the morphological-phonological interface and we have identified and defined the various computational phonological parameters necessary to create a lexicon architecture that is sufficiently rich and universal in nature to capture the linguistic phenomena persistent to ISL. In order to adequately represent a grammatically coherent and credible Sign Language utterance in computational terms, we must consider the behaviour of these MF and NMF phonological parameters in relation to temporal information. We have proposed that *event duration* and *timeline* parameters will play a central role within our computational framework as these parameters will be responsible for the management of the ordering or sequence in which each phonological parameter event will be realised.

It is anticipated that these parameters will enable the realisation of a credible, plausible and comprehensible ISL utterance articulated in 3D space. We have also proposed parameters for handshape, orientation, hand movement, forearm, upper arm and location. The location parameter has been subdivided into spatial and body anchored parameters and each of these subcategories have been rigorously defined. We have also defined parameters that are necessary to accommodate information pertinent to NMF.

Further to this we have proposed that with regard to GL theory (Pustejovsky, 1991), that we must extend the levels of representation for lexical meaning specific to signed languages. We propose that we add a fifth level: *Phonological Structure*. This new level representing the phonological structure will be utilised to accommodate information pertinent to Sign Language that must be captured to truly represent the lexical meaning of signs.

Further investigation and consideration must be given to the development of our linguistically motivated computational framework architecture. Questions relating to where the various 66 handshapes of ISL will reside within the architecture are currently being researched. On analysis of these handshapes we have identified that 24 out of the 66 handshapes carry grammatical meaning. 42 of these handshapes carry no grammatical meaning without

applying some other phonological rule to the handshape. It is proposed at this point that the various phonemes and morphemes will be stored in separate inventories within our framework.

The next and final stage of this research will be the investigation and the description of the linking system from the lexicon to include our extended lexical representation level into spatial visual syntax for ISL nouns and verbs. We will also investigate the ISL sentence and operator representation within our proposed lexicon architecture.

9 References

- Battison, R. (1974). "Phonological deletion in American Sign Language". *Sign Language Studies*, v. 5, p. 1-19.
- [Blender] (Available at 08 April 2015) www.Blender.org
- Brennan, M. (1992). "The visual world of BSL: an introduction", In: D. Brien (ed.), *dictionary of British Sign Language/English*, Faber and Faber, London, UK. pp. 1-134.
- Brennan, M. (1994). "Word order: Introducing the issues", In: M. Brennan and G. H. Turner (ed.), *Word order issues in Sign Language*, Durham: International Sign Linguistics Association. pp. 9-46.
- Johnston, T. and Schembri A. (1999). "On Defining Lexeme in a Signed Language". In: *Sign Language & Linguistics* 2(2), page 115-185.
- Klima, E. S. and Bellugi U. (1979). "The Signs of Language" Harvard University Press. Cambridge MA and London.
- Kronlid, F. (2003). "Modes of explanation - Aristotelian Philosophy and Pustejovskyan Linguistics". Unpublished Thesis, University of Gteborg, Sweden.
- Levin, B. (1993) "English Verb Classes and Alternations", Cambridge University Press, Cambridge, UK.
- Leeson, L. and Saeed J. (2012). "Irish Sign Language" Edinburgh University Press, Edinburgh, UK.
- [MakeHuman] (Available at 08 April 2015) www.MakeHuman.org
- McDonnell, P. (1996 a). *Verb Categories in Irish Sign Language*. Unpublished doctoral dissertation. Centre for Language and Communication Studies (CLCS), University of Dublin, Trinity College, Dublin, Ireland.
- Meir, I. (2012) "Word classes and word formation". In: *Sign Language: An International Handbook*, eds. R. Pfau, M. Steinbach, B.Woll, Berlin: Mouton de Gruyter
- Murtagh, I. (2011a). *Developing a Linguistically Motivated Avatar for ISL Visualisation*. Workshop on Sign Language Translation and Avatar Technology, University of Dundee 2011. Dundee, Scotland.
- Murtagh, I. (2011c). *Towards an RRG-enabled Irish Sign Language Avatar*. Paper presented at the International Conference on Role and Reference Grammar on "Functional Linguistics: Grammar, Communication & Cognition". Facultad de Letras, at the Pontificia Universidad Católica de Chile, in Santiago de Chile.
- O'Baoill, D. and Matthews, P. A. (2000). "The Irish Deaf Community (Volume 2): The Structure of Irish Sign Language". The Linguistics Institute of Ireland, Dublin, Ireland.
- Padden, C. (1988). *Interaction of Morphology and Syntax in American Sign Language: Outstanding Dissertations in Linguistics, Series IV*. New York: Garland Press.
- Pustejovsky, J. 1991. "The Generative Lexicon". *Computational Linguistics*, Volume 17(4), pp. 209-441.

- Stokoe, W. (1960). “*Sign Language Structure: An Outline of the Visual Communication System of the American Deaf*”, In: Studies in Linguistics Occasional Paper 8, University of Buffalo. Revised 1978 Lincoln Press.
- Sutton-Spence R and Woll B. (1999). *The Linguistics of British Sign Language; an introduction*. Cambridge University Press.
- Taub, S. F. (2001). “*Language from the Body: Iconicity and Metaphor in American Sign Language*”. Cambridge: Cambridge University Press.
- Thorvaldsdottir, G. (2010). “*You get out what you put in: The beginnings of phonetic and phonological coding in the Signs of Ireland digital corpus*”. Paper presented at the LREC, Malta, 17 – 23 May 2010.
- Valli, C. and Lucas, C. (1995). “*Linguistics of American Sign Language*”, 2nd Edition, Gallaudet University Press.
- Zenshan, U. (2007). Towards a notion of ‘word’ in sign languages. In Dixon, R.M. W and A. Y. Aikenvald. *Word: A cross-linguistic typology*. Cambridge: Cambridge University Press.
- Zwitserslood, I. (2012). “*Classifiers*”. In: eds. R. Pfau, M. Steinbach, B. Woll, “*Sign Language: An International Handbook*”, Mouton de Gruyter, Berlin.